



# **ODS-EUROFER - A Reduced Activation Ferritic Martensitic ODS-Steels for Application in Advanced Blanket Concepts**

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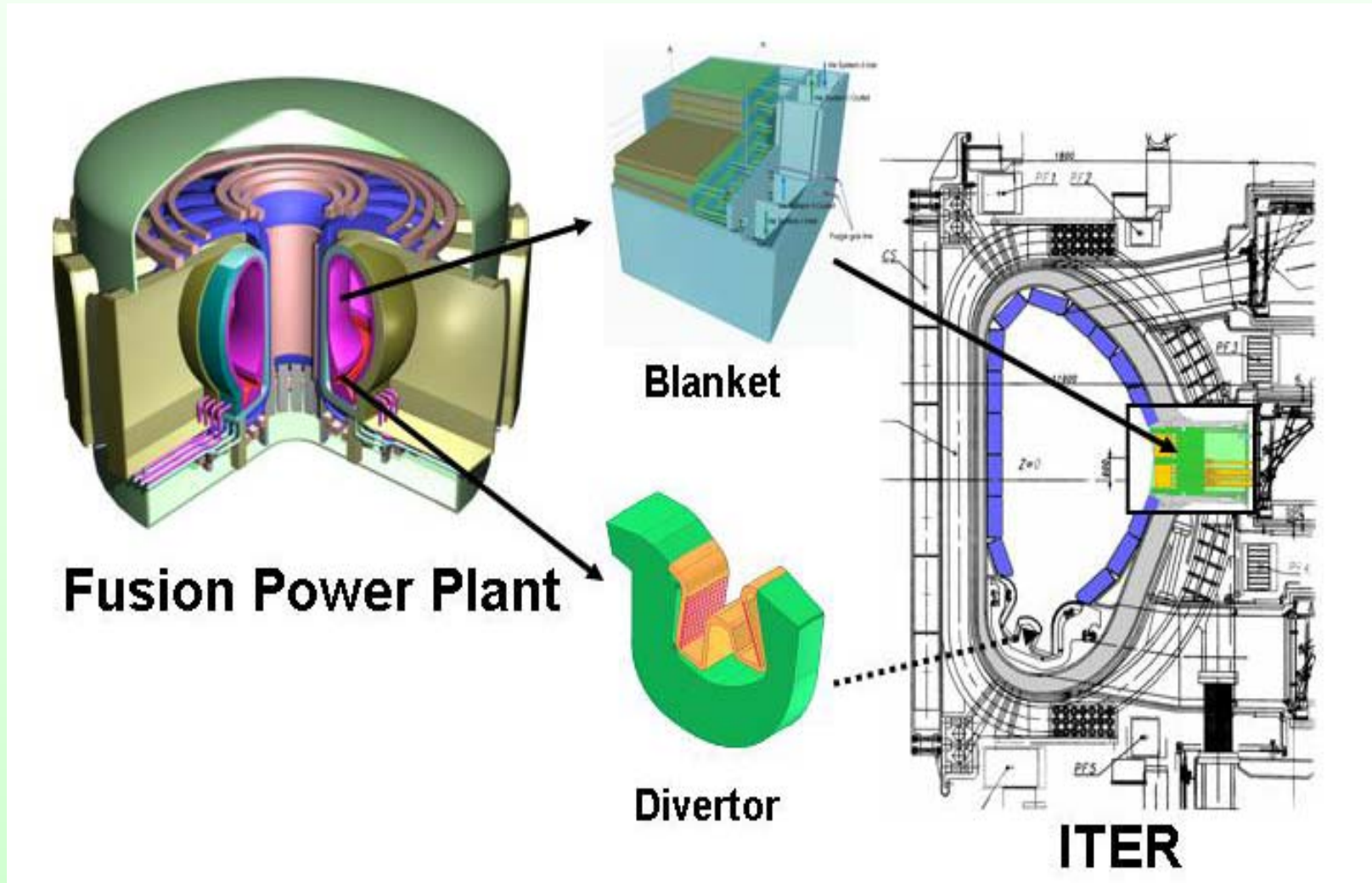


## Outline

- **Introduction**
  - Devices
  - Activation Behaviour
- **Reduced Activation Ferritic Martensitic (RAFM)**  
**9%Cr ODS steel ODS-EUROFER**
- **Production of ODS-EUROFER**
- **Microstructure of ODS-EUROFER**
- **Mechanical properties of ODS-EUROFER**  
Tensile-, Creep-, Impact-properties
- **Joining of ODS-EUROFER**
  - Diffusion welding, alternative joining methods
- **Reduced Activation Ferritic 12-14% Cr ODS steels**
- **First irradiation results**

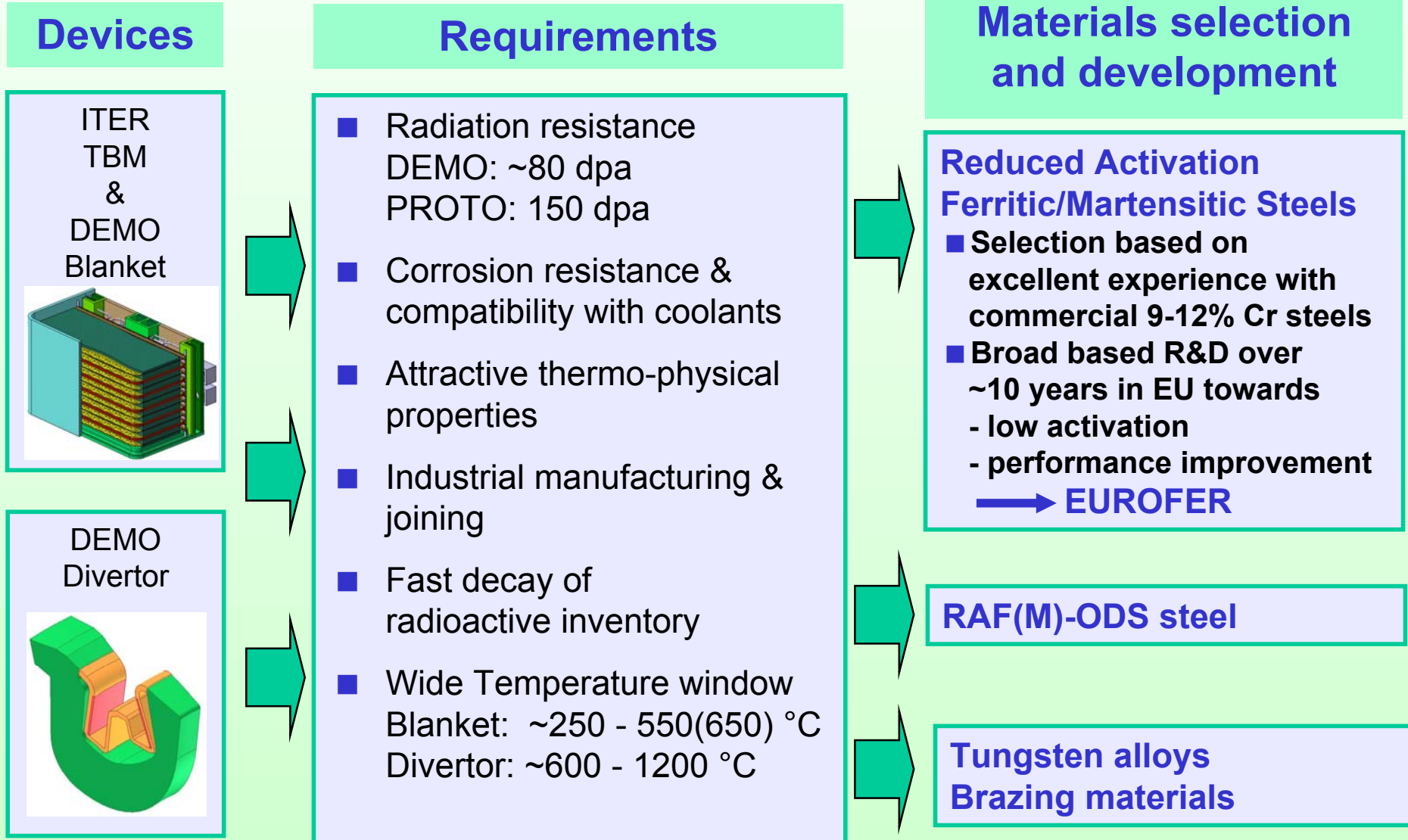


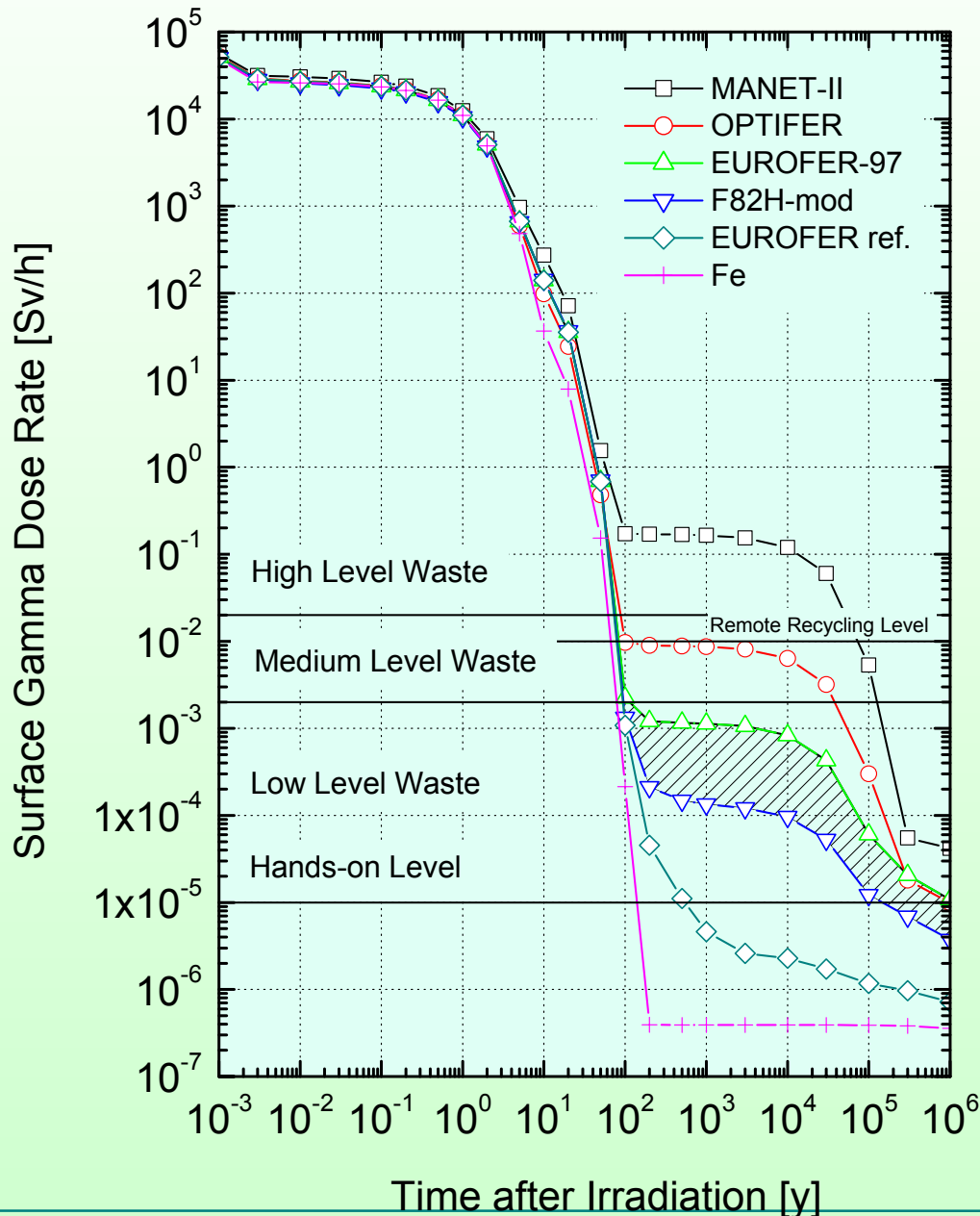
## Mission driven structural materials development





## Mission driven structural materials development





## Priority: Low activation

Long term irradiation  
(12.5 MWa/m<sup>2</sup>) of a  
DEMO reactor first wall

- Huge progress in the development of reduced activation FM steels:
- „Low level waste“ already after ~100 years
- No “high level” waste disposal
- The impurities Nb and Mo are dominating the hatched area



## Basic Composition of ODS-EUROFER

RAFM Steels:

Replace critical alloying elements e.g. Nb  $\Rightarrow$  Ta, Mo  $\Rightarrow$  W

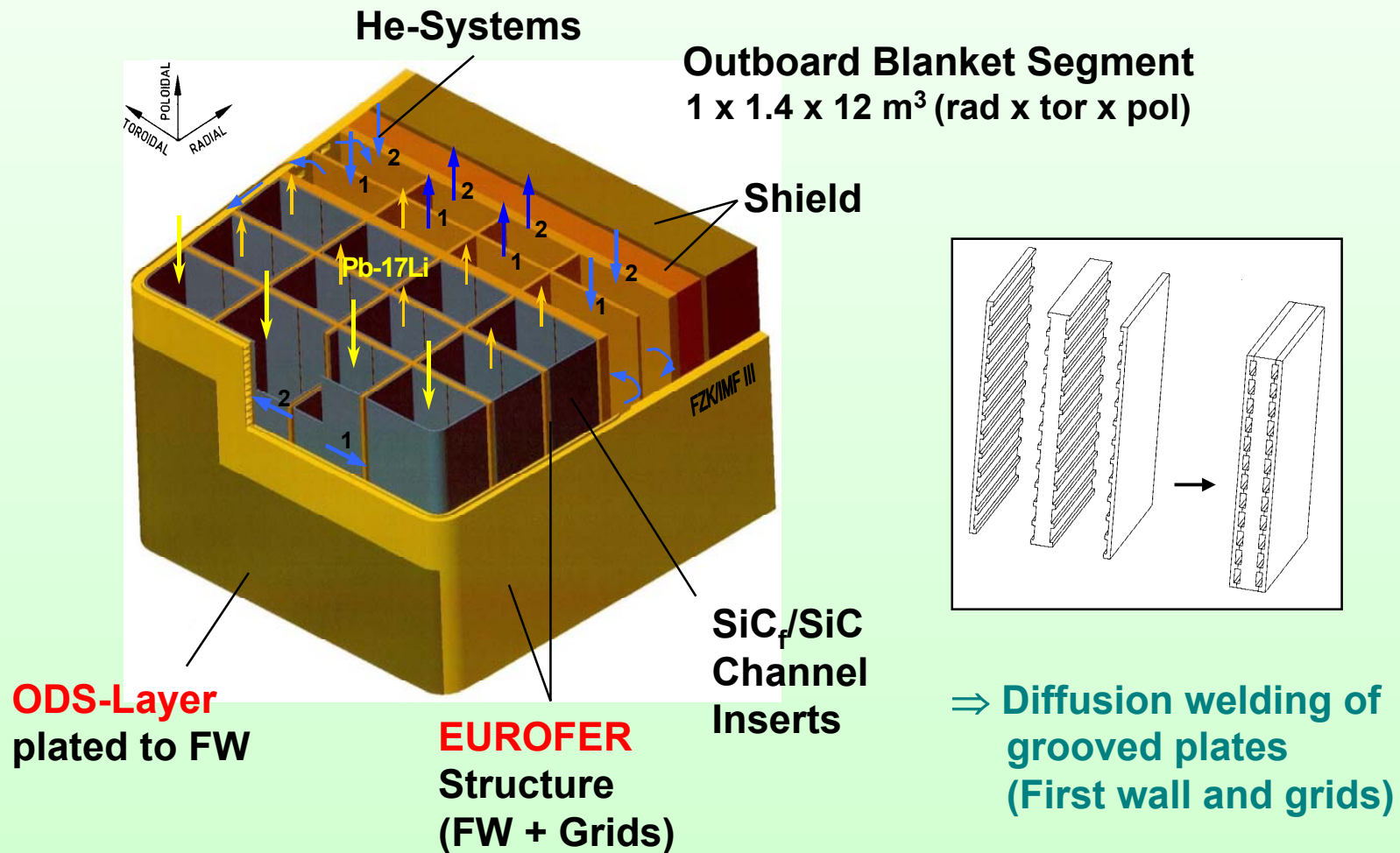
Alloy	Heat	C	Si	Mn	Cr	V	W	Ta	+	Y <sub>2</sub> O <sub>3</sub>
EUROFER	E 83699	0.12	0.06	0.42	8.87	0.19	1.10	0.14		0.3 or 0.5

All values in wt.-%

Nb, Mo, Ni, Cu, Al, Co restricted to ppm-values

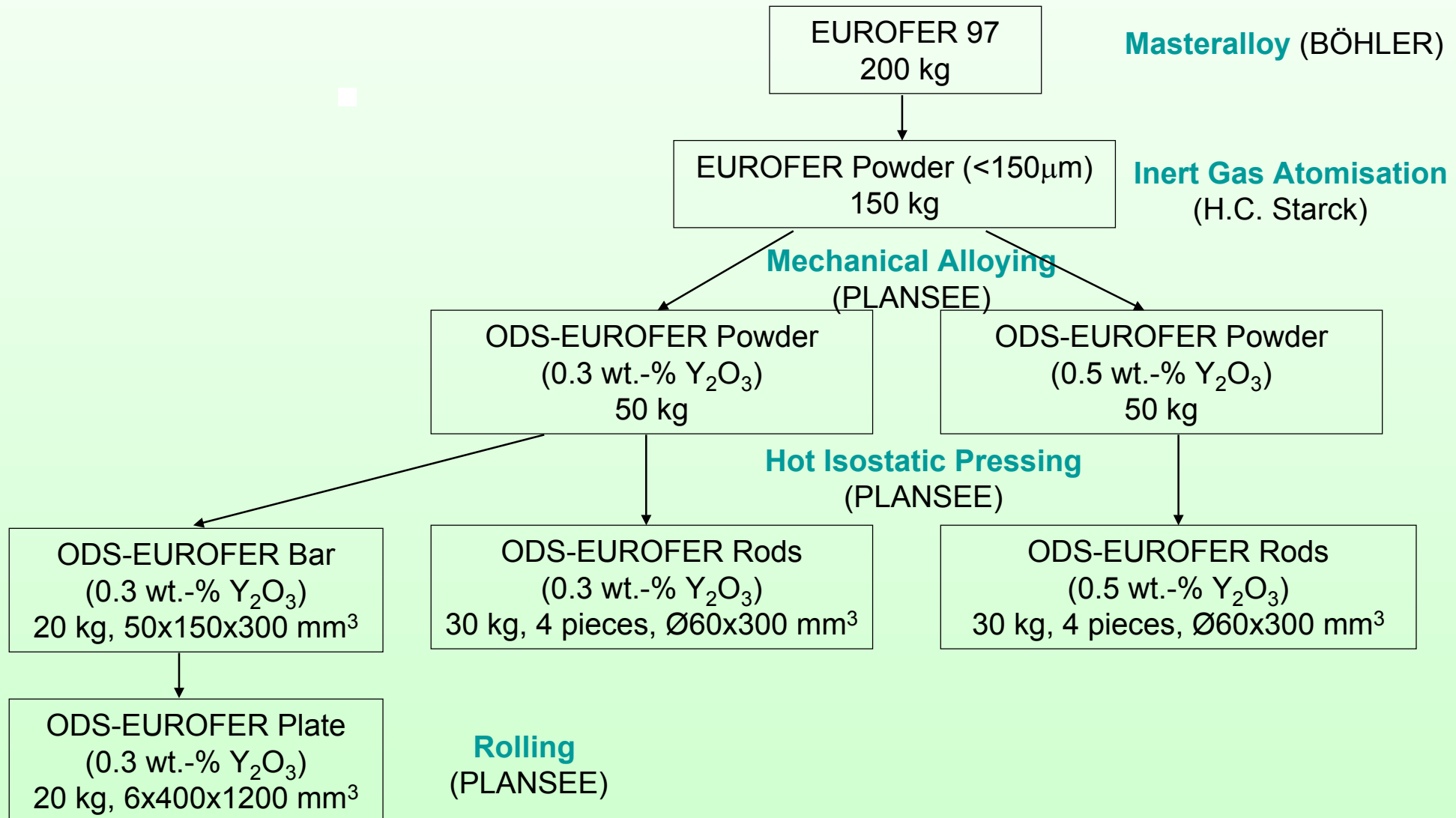


## Dual-Coolant Pb-Li/He Blanket



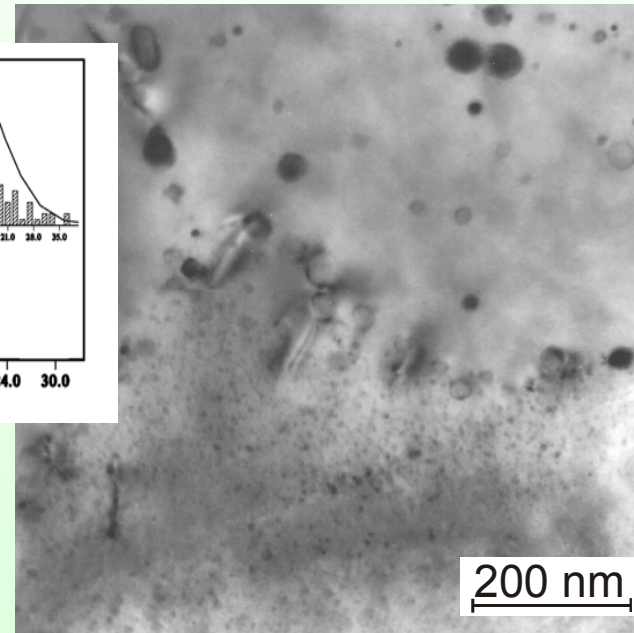
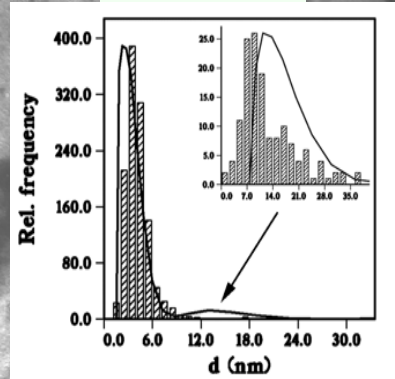
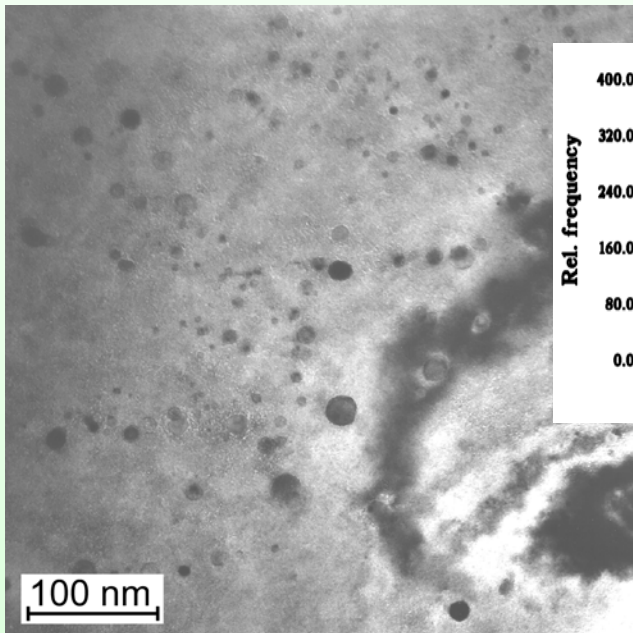


## Production of ODS-EUROFER

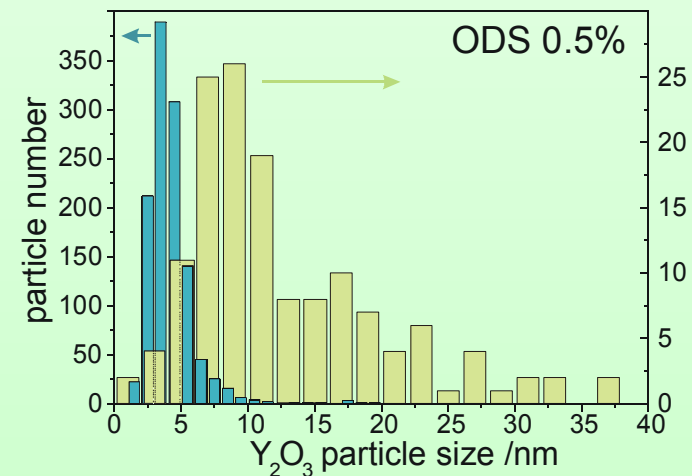
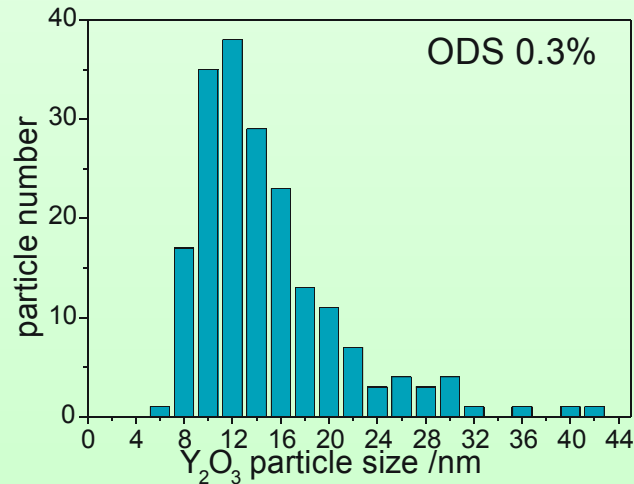




## Y<sub>2</sub>O<sub>3</sub> particles - spatial and size distribution

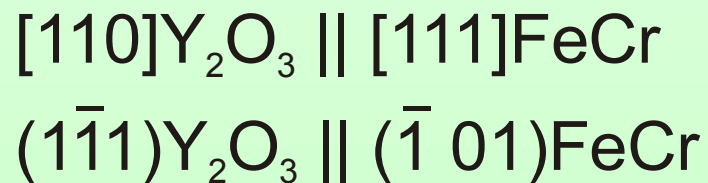
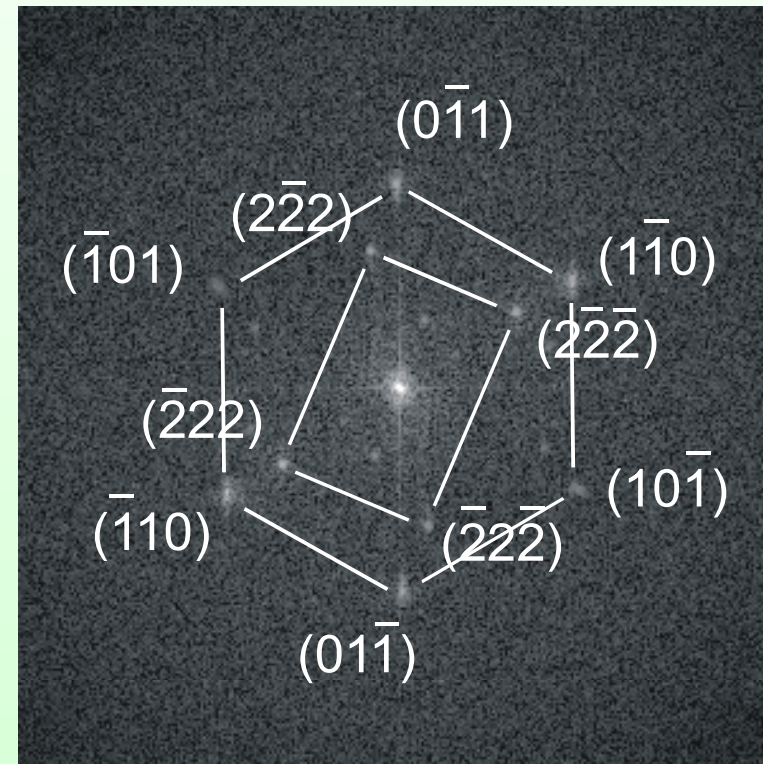
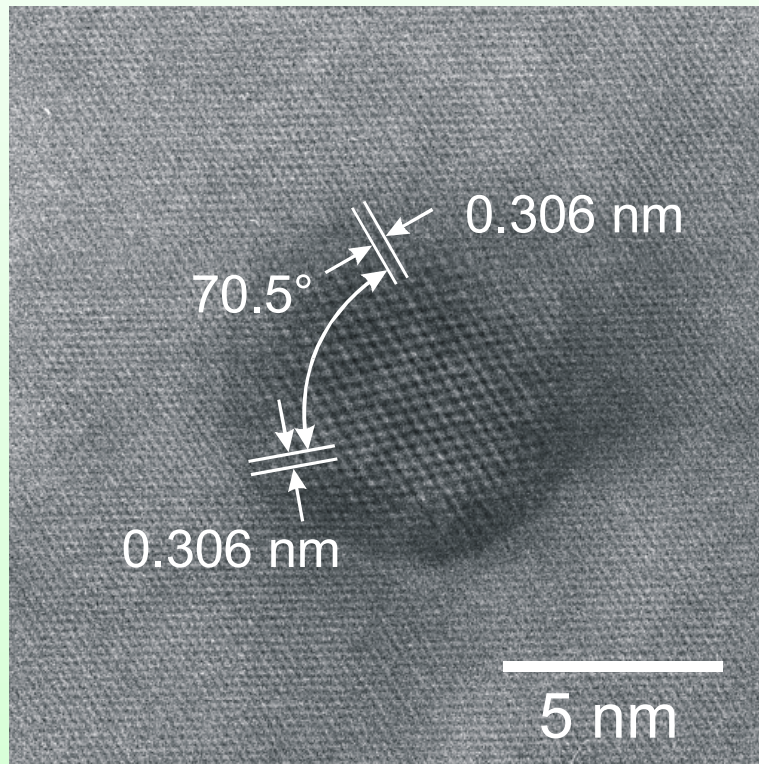


SANS  
R. Coppola  
ENEA



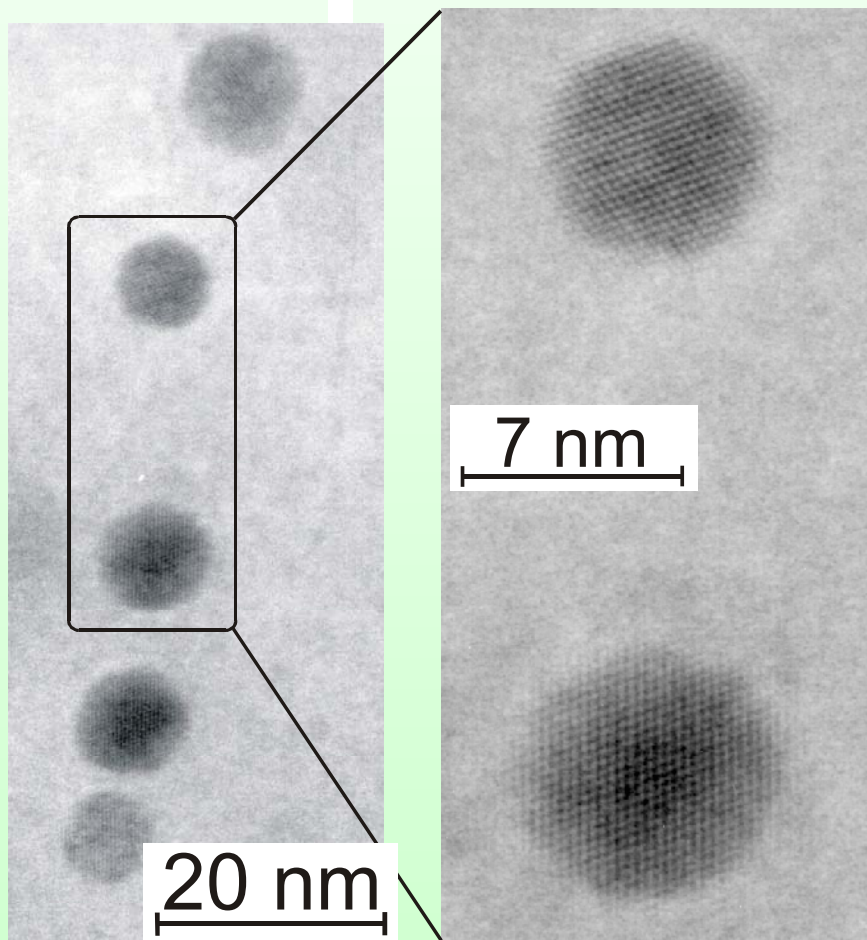


## Orientation relationship of $Y_2O_3$ particles and matrix

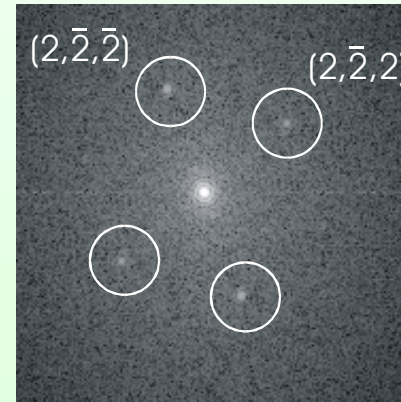




## Correlation of crystalline orientation of $Y_2O_3$ particles

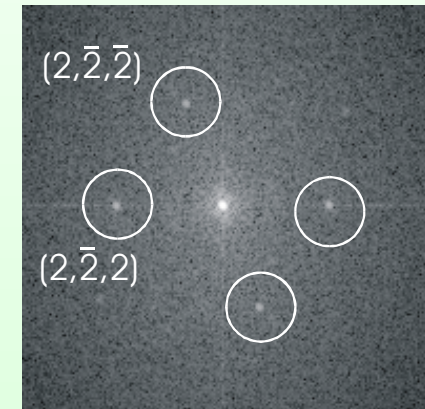


FFT upper particle



$[\bar{1}\bar{1}0]$  - zone axis  
 $d_{(222)} = 0.306$  nm

FFT lower particle



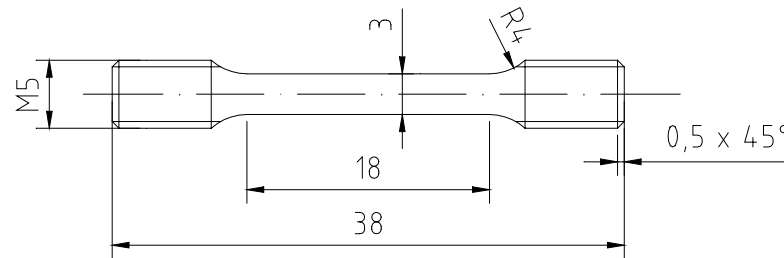
$[110]$  - zone axis  
 $d_{(222)} = 0.306$  nm

FFT both particles



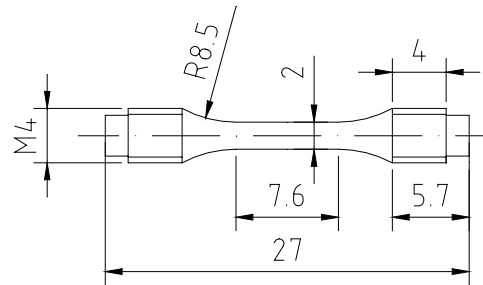


## Specimen Geometries



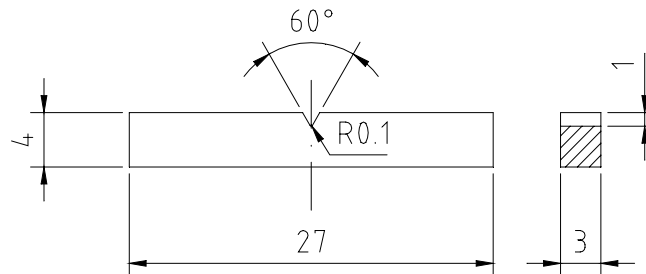
Creep

SSTT



Tensile,  
LCF

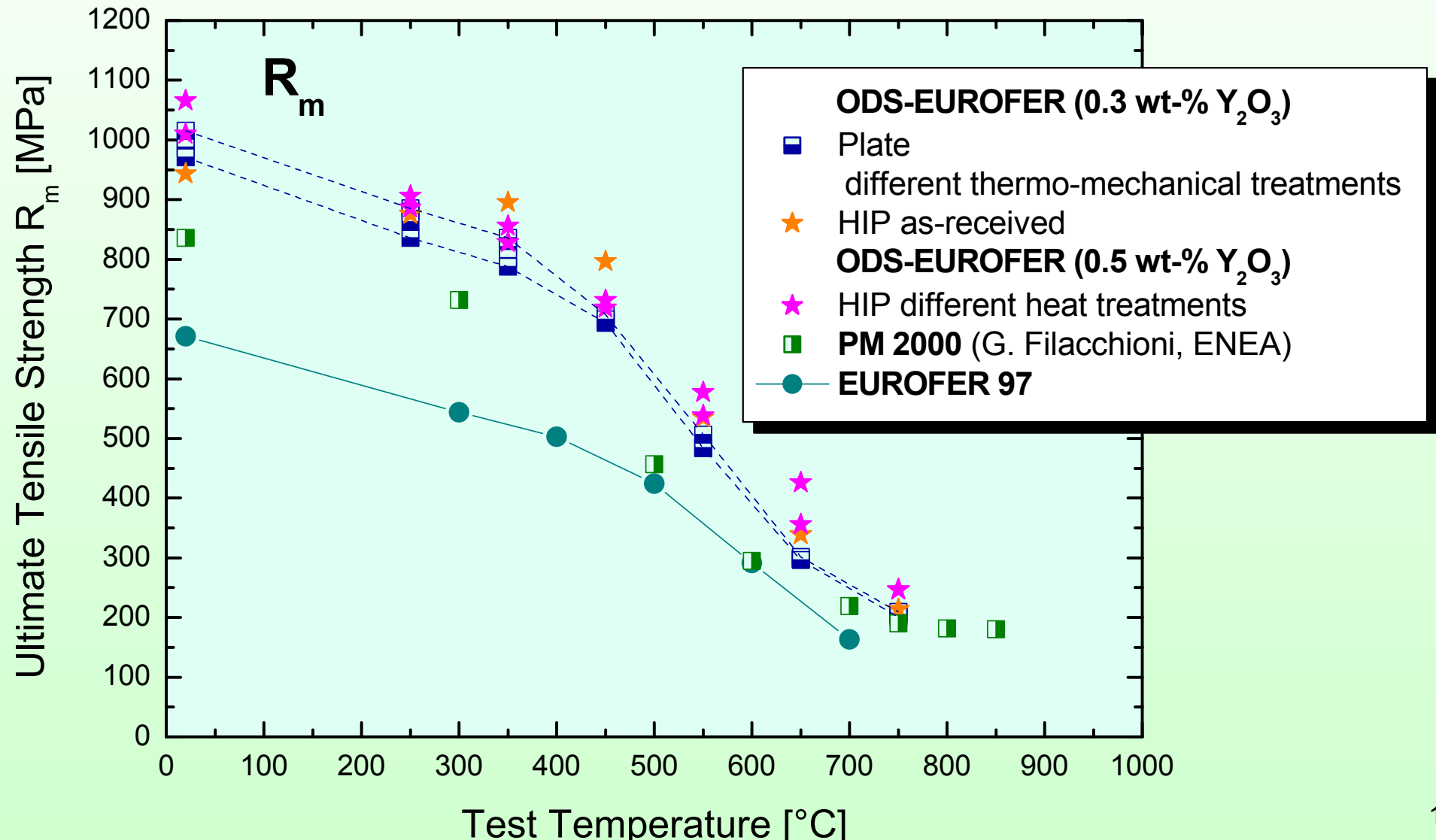
KLST  
acc. DIN 50115



Charpy

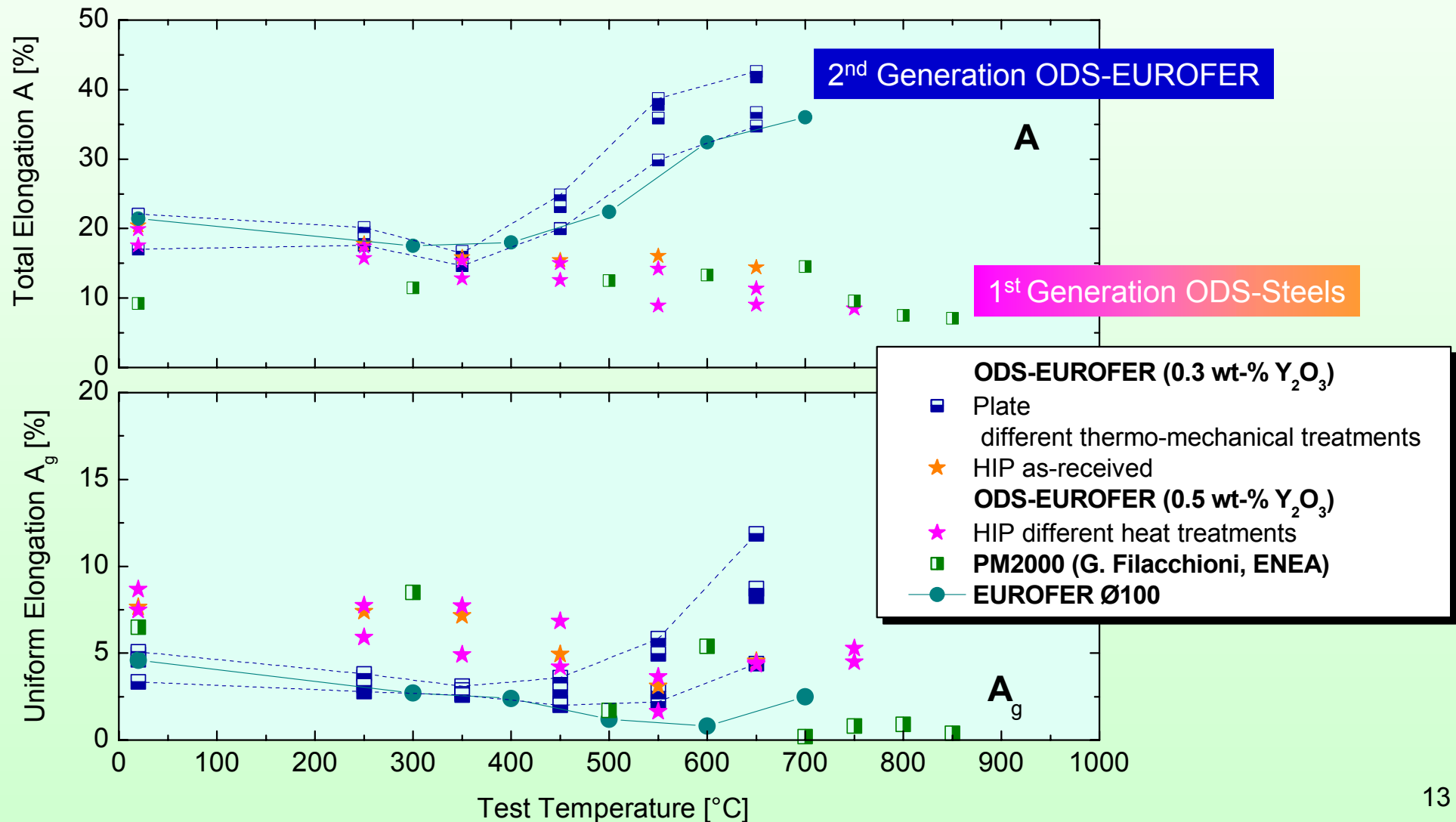


## Ultimate Tensile Strength $R_m$ of ODS-EUROFER





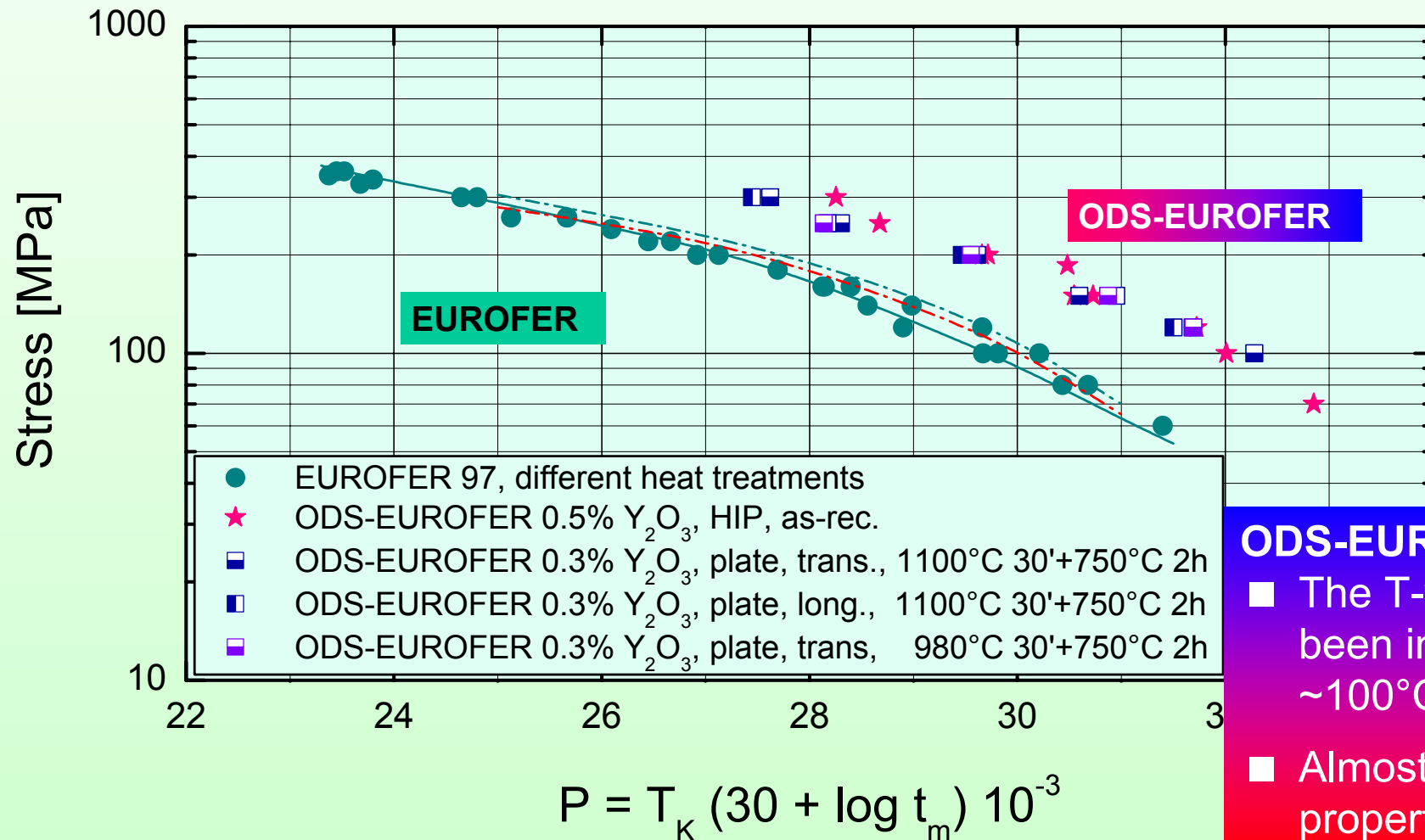
## Total and Uniform Elongation of ODS-EUROFER





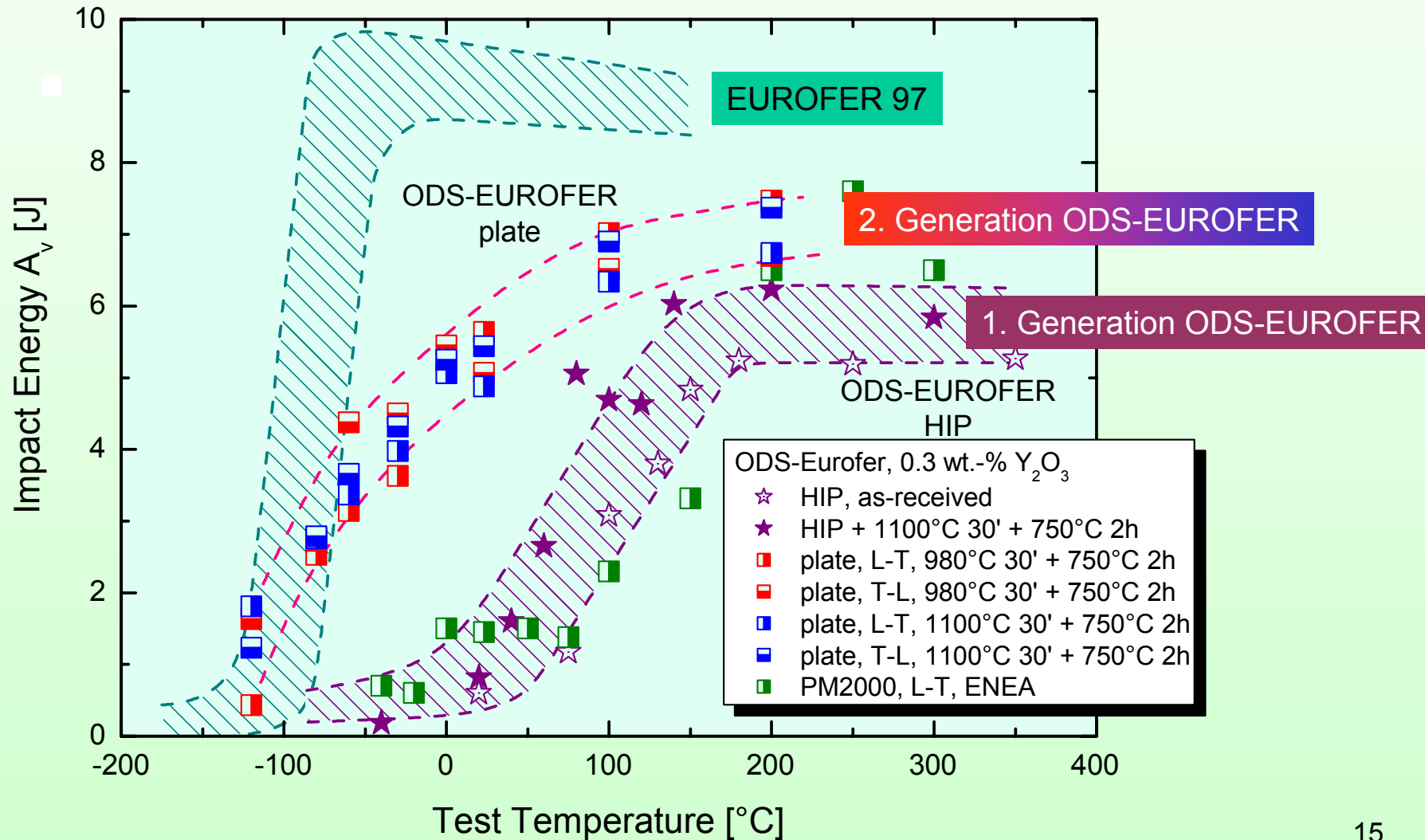
## Creep Behaviour of ODS-EUROFER compared to EUROFER 97

Master-Curve  
(Larson-Miller-Parameter)





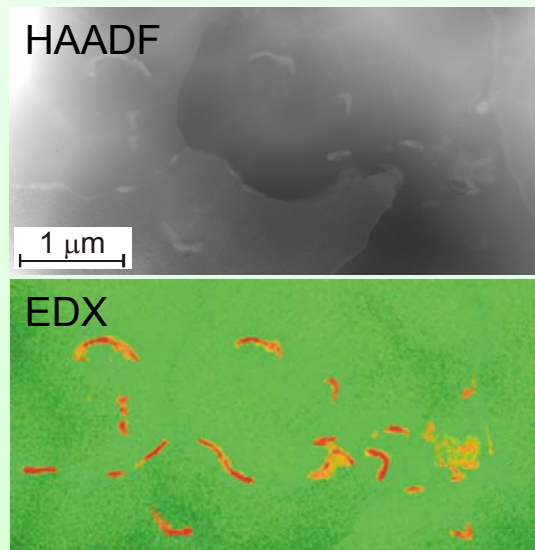
## Instrumented Impact Tests on KLST Specimens: Energy Values and Comparison with EUROFER 97



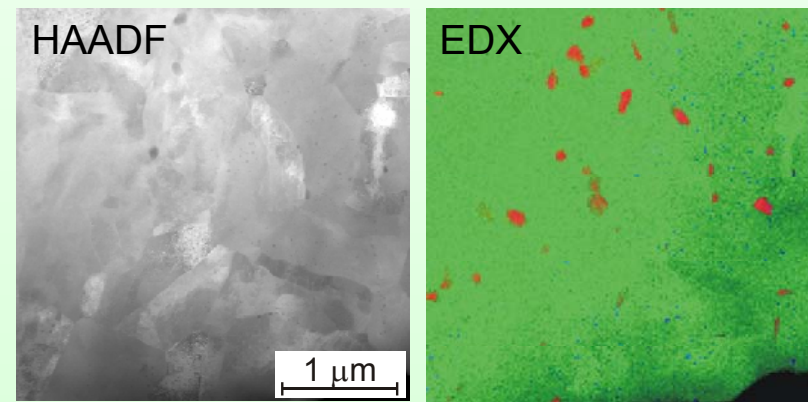


## Cr-rich phases in ODS-EUROFER

as-hipped



thermomechanical treatment

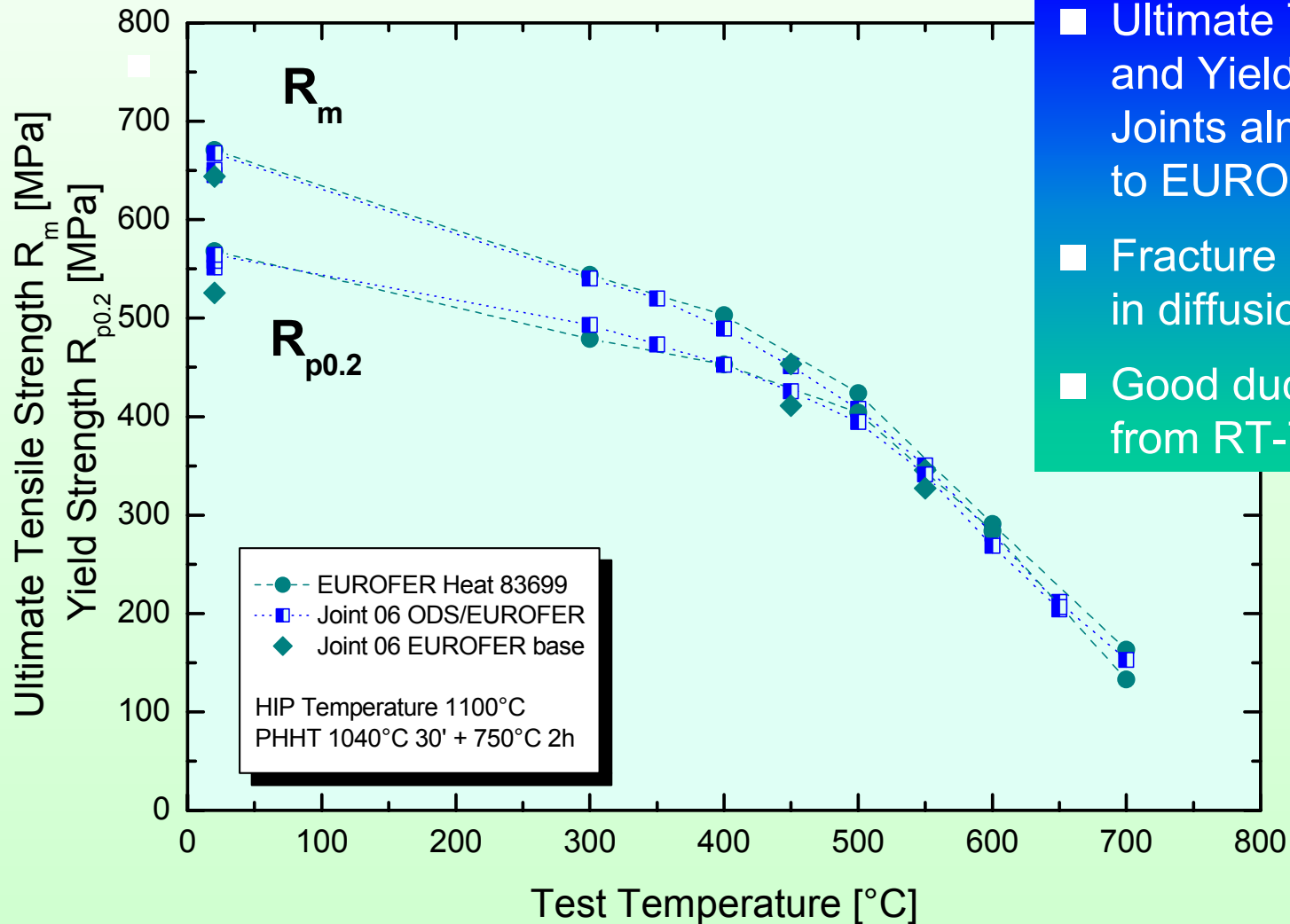


■ Fe/Cr 91% / 9%

■ Fe/Cr 50% / 50%



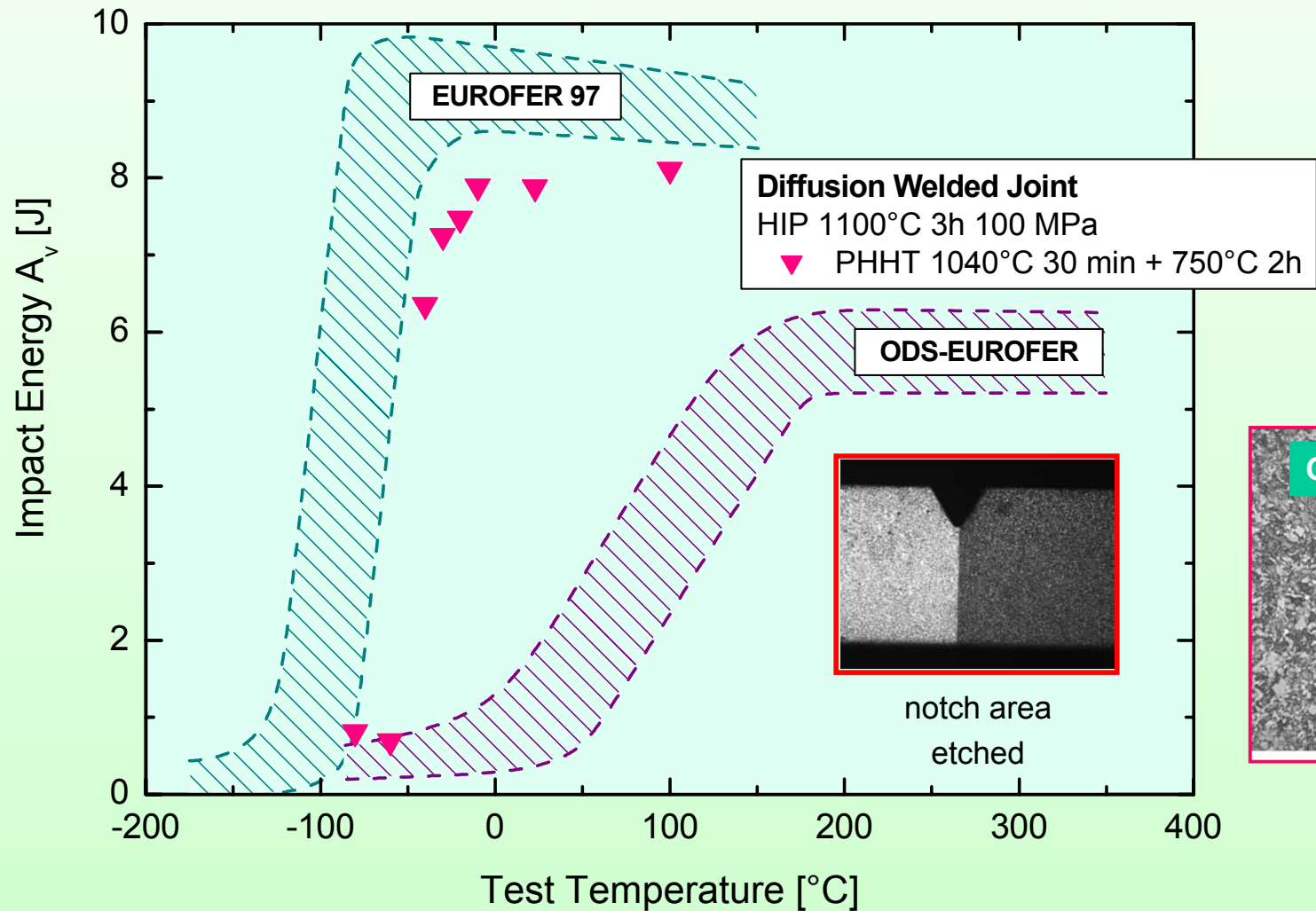
## Tensile Properties of diffusion-welded ODS-EUROFER – EUROFER Joints



- Ultimate Tensile Strength and Yield Strength of Joints almost identical to EUROFER 97 base
- Fracture never occurred in diffusion bond
- Good ductility from RT-700°C

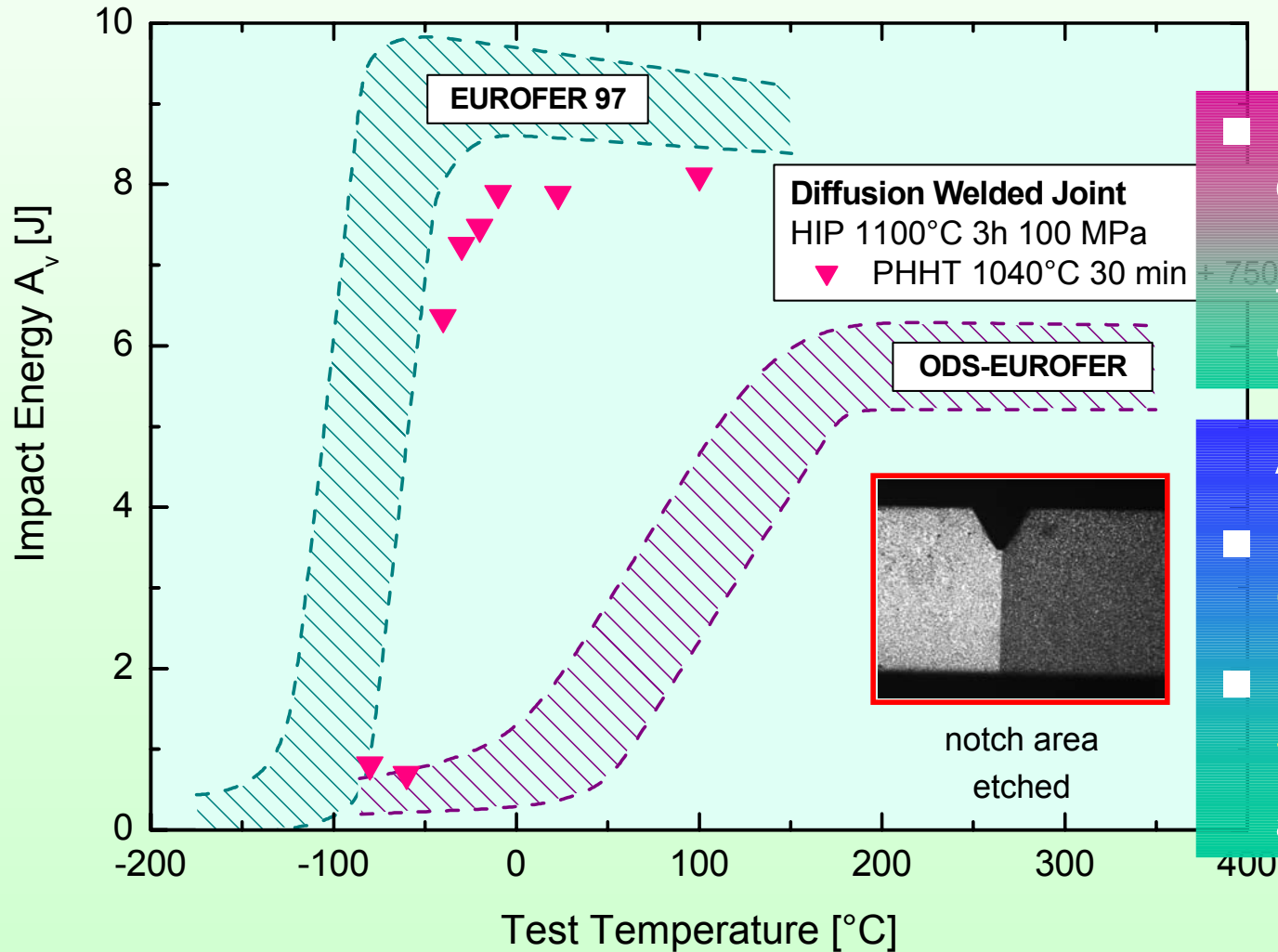


## Impact Properties of diffusion-welded ODS-EUROFER – EUROFER Joints





## Impact Properties of diffusion-welded ODS-EUROFER – EUROFER Joints



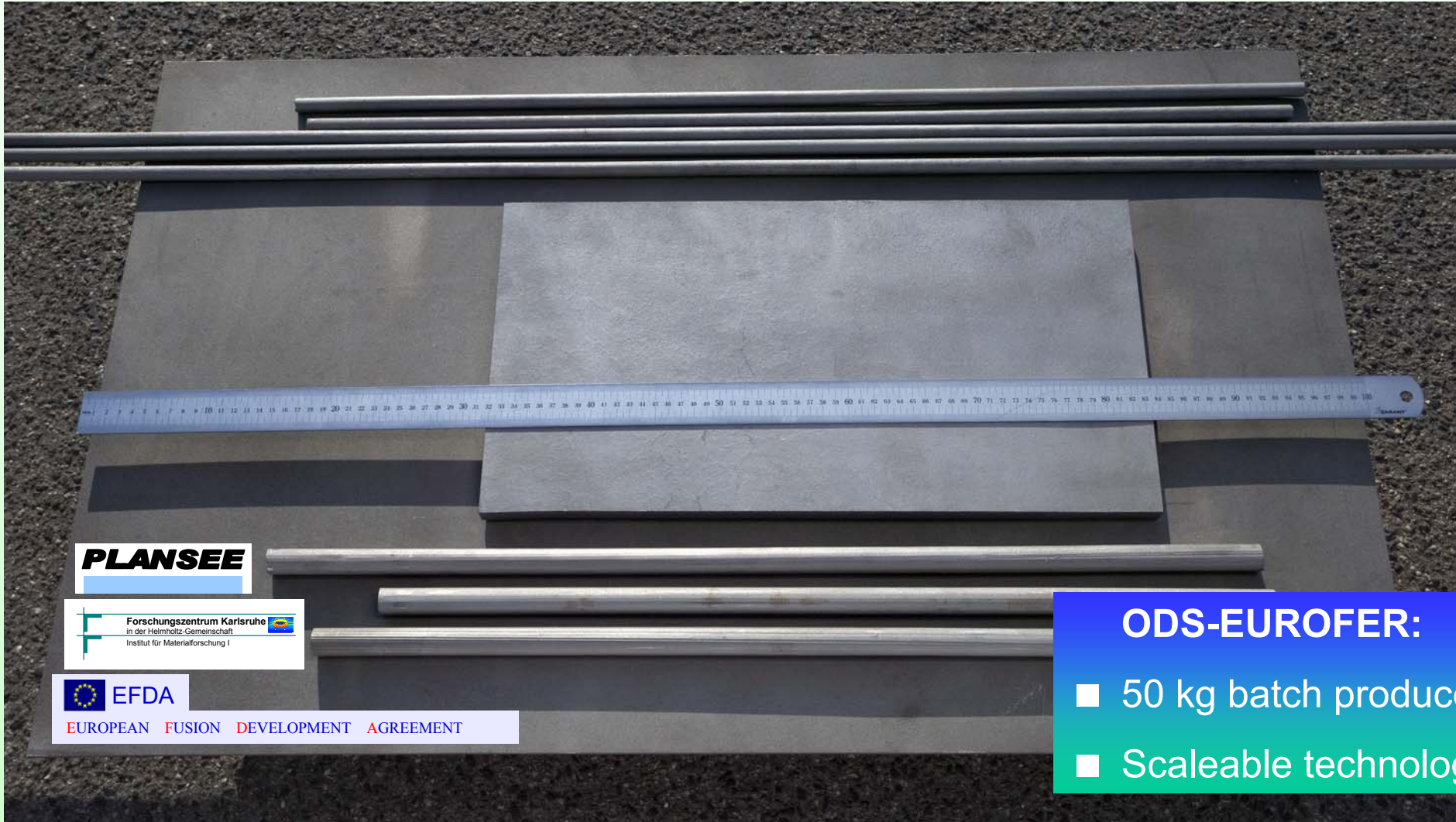
Impact properties of joints closer to EUROFER 97 base than to ODS base material

Alternative methods:

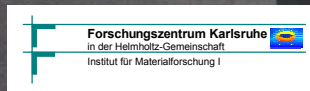
- Friction Stir Welding  
Grant et al. PNNL
  - Resistance welding  
Seki et al. JNC
- also promising



## Products of EU ODS-EUROFER



**PLANSEE**



EUROPEAN FUSION DEVELOPMENT AGREEMENT

### ODS-EUROFER:

- 50 kg batch produced
- Scalable technology



## Chemical composition of some RAF ODS batches

Alloy	Cr	W	Ti	Y <sub>2</sub> O <sub>3</sub>
12YWT	12.3-12.6	2.44-3.0	0.35-0.39	0.25
J12YWT	13	3	0.4	0.25
U14YT	14	-	0.4	0.25
U14YW	14	3	-	0.25
U14YWT	14	3	0.4	0.25
O14YWT	14.2	1.95	0.4	0.25

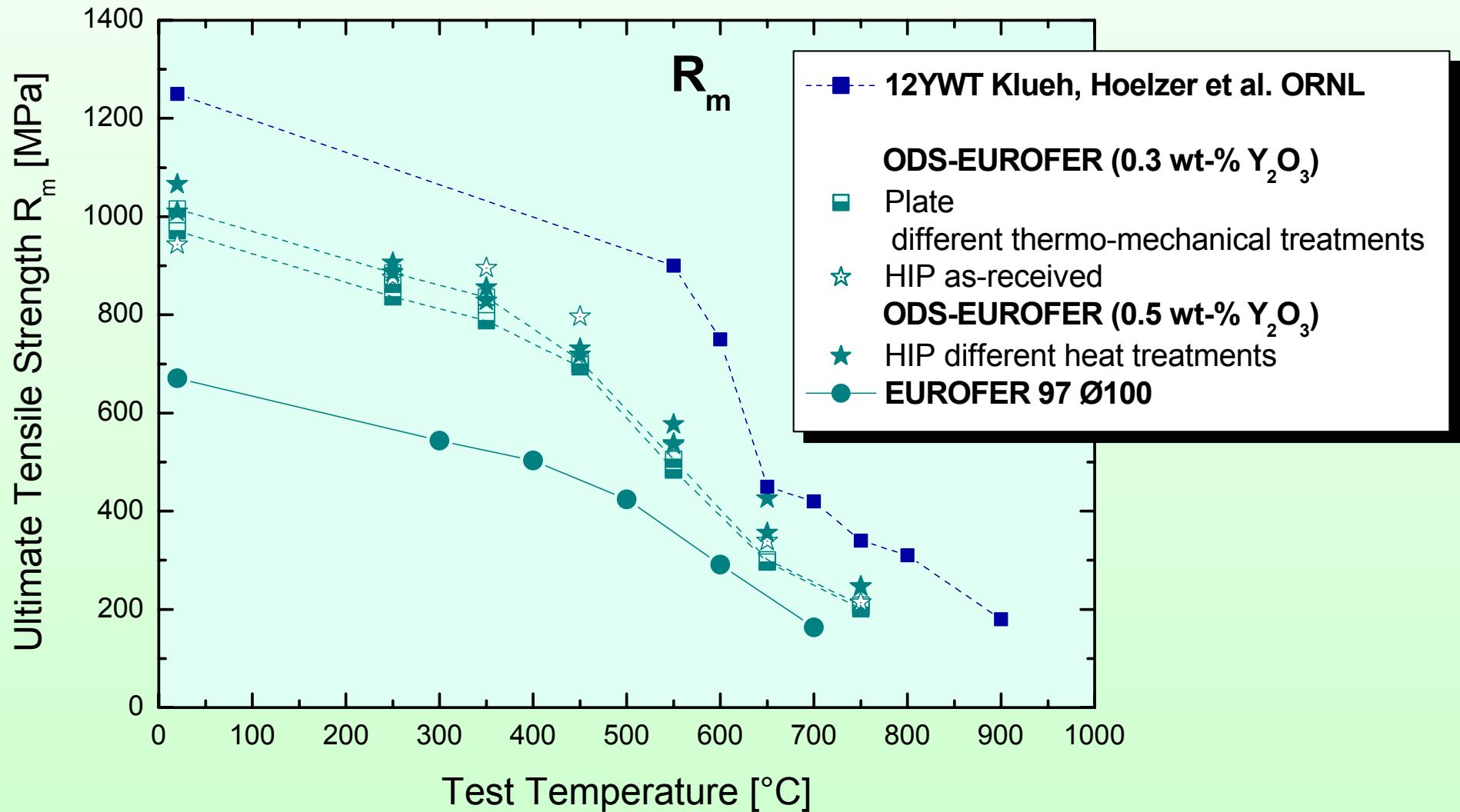
N. Baluc, CRPP  
U=UCSB, O=ORNL

Ti additions:

- Reduce excess oxygen content
- Promote the formation of (Y,Ti,O) nano-clusters

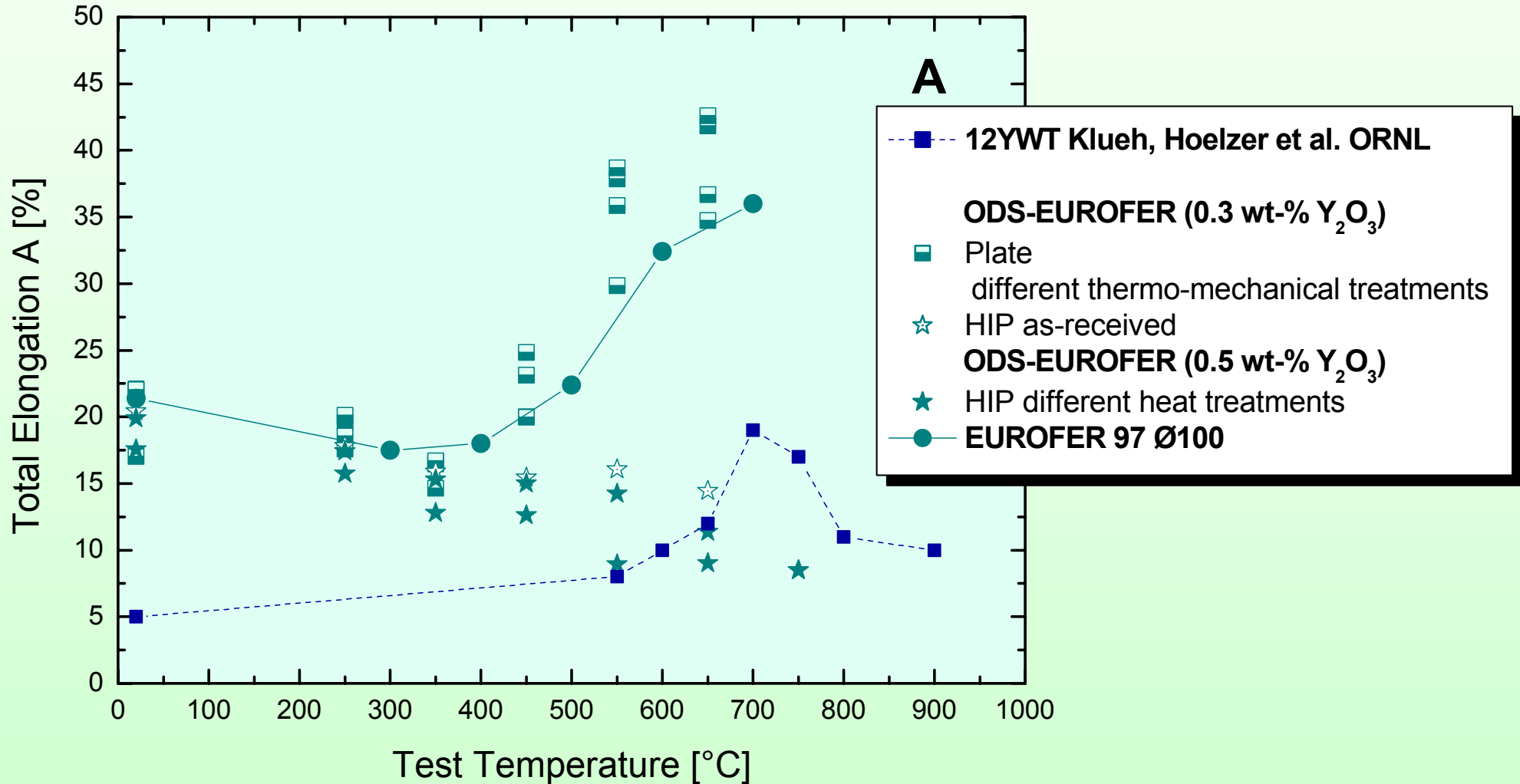


## Ultimate Tensile Strength $R_m$ of ODS-EUROFER and 12YWT





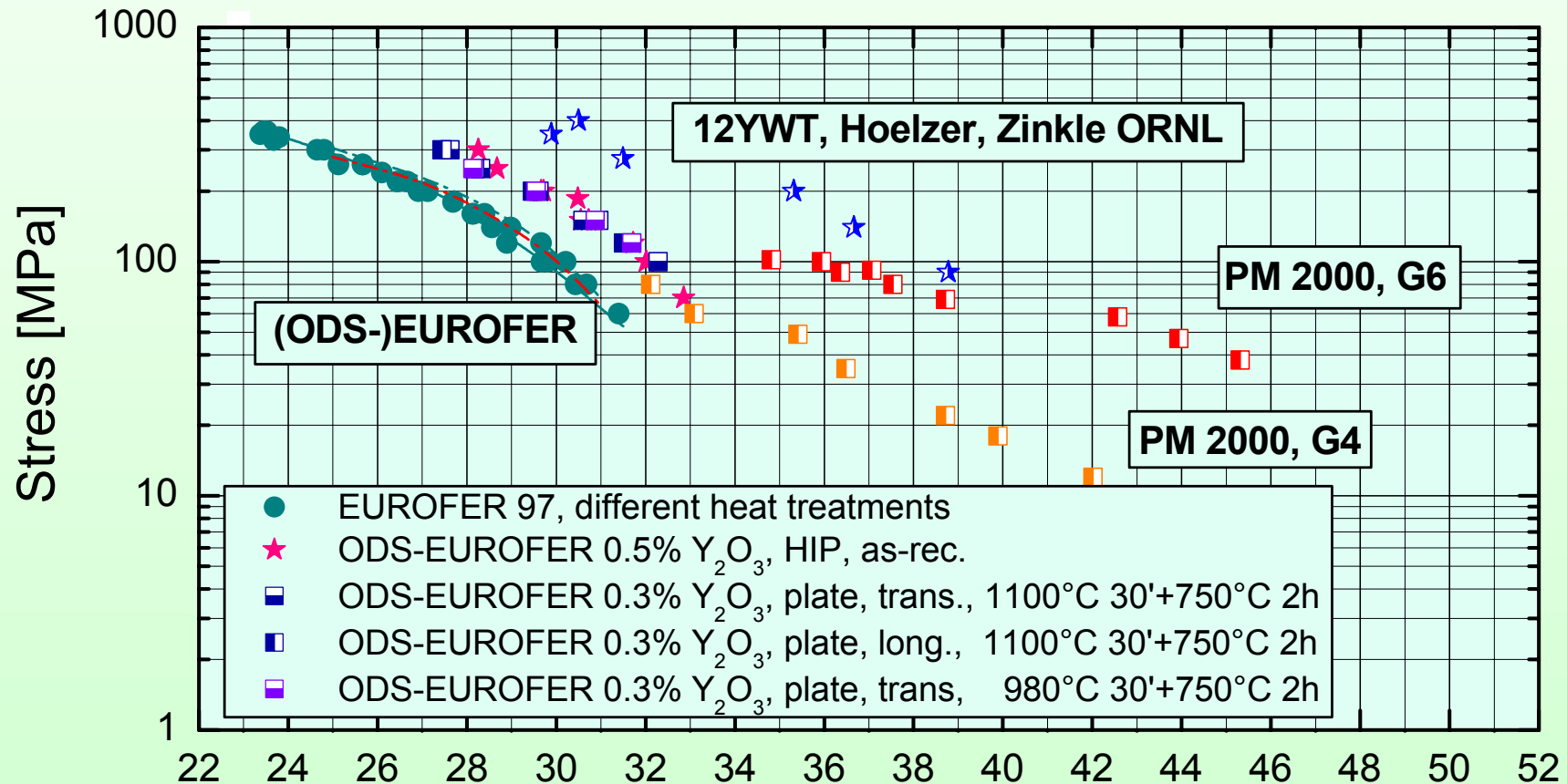
## Total Elongation A of ODS-EUROFER and 12YWT





## Creep Behaviour of 12YWT, PM 2000 and ODS-EUROFER

Master-Curve  
(Larson-Miller-Parameter)



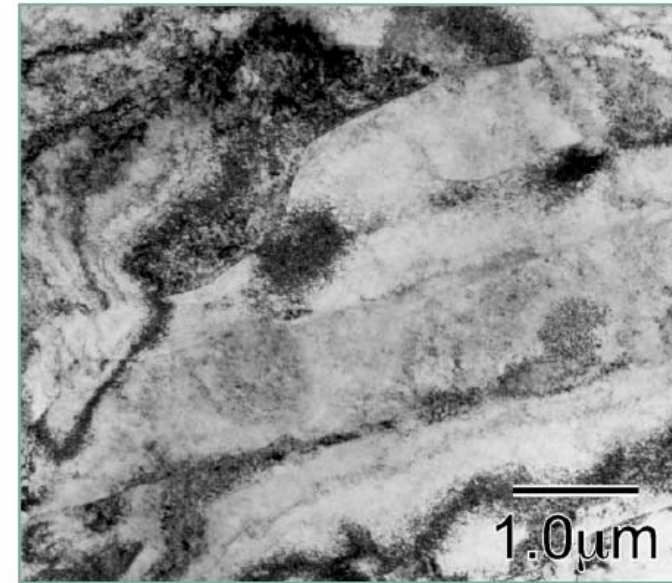
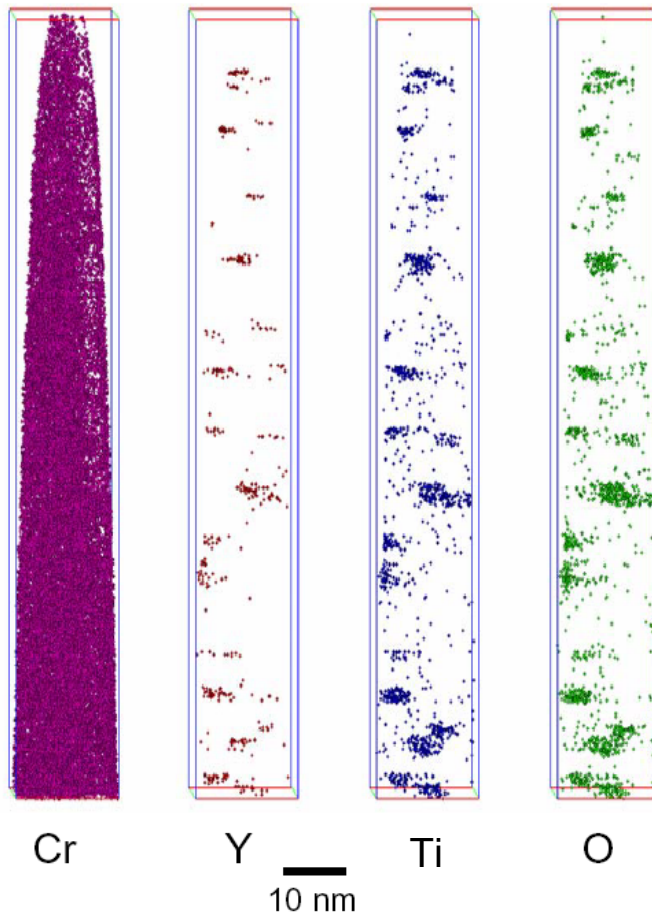
$$P = T_K (30 + \log t_m) 10^{-3}$$



## Nanocomposited Ferritic (NCF) Steel

(MA Fe-12Cr-3W-0.4Ti + 0.25Y<sub>2</sub>O<sub>3</sub> : 12YWT) Miller, Hoelzer, Zinkle ORNL

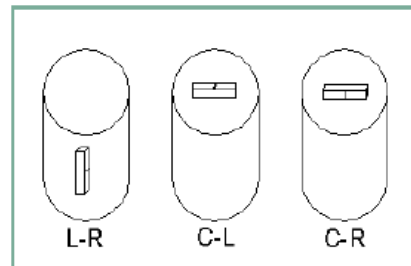
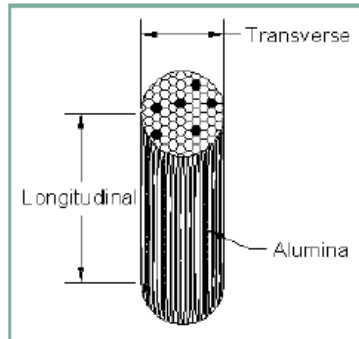
3-D Atom Probe Tomography



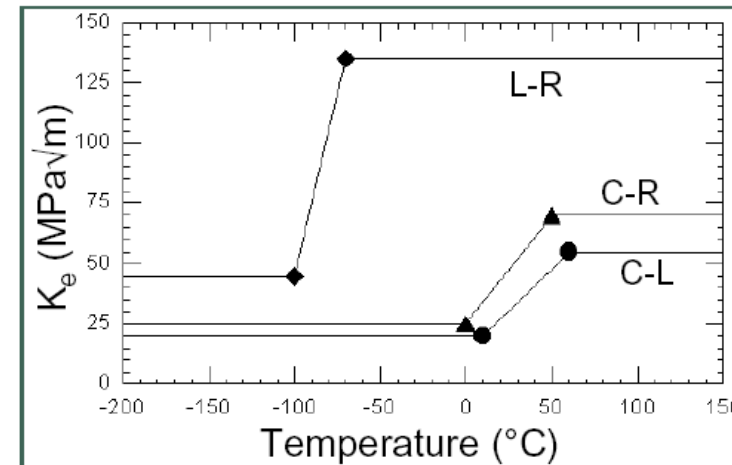
- very high number density of  $\sim 10^{24}/\text{m}^3$  of uniformly distributed nanoclusters
  - site occupancy on bcc Fe lattice
  - average size  $r_g = 2.0 (+/- 0.8)$  nm
- elongated grains containing high dislocation number density (TEM)



## Low Temperature Toughness Behavior in MA957



1/3-sized Charpy Specimens



- Fracture toughness trends reflect the microstructural anisotropy in the longitudinal direction (*parallel to extrusion direction*)
  - correlated with 10:1 aspect ratio of grain size and  $\text{Al}_2\text{O}_3$  stringers
  - highest toughness is achieved when the crack propagates orthogonal to elongated grains and  $\text{Al}_2\text{O}_3$  stringers - (*L-R orientation*)

(Odette, Alinger: UCSB)



## Ongoing work on RAF-ODS steels in Europe

Alloy	Fe	Cr	W	Ti	Y <sub>2</sub> O <sub>3</sub>
FZK14YWT	rem.	14	1.2	0.2-0.3-0.4	0.3
FZK14YWT	rem.	14	2	0.2-0.3-0.4	0.3
CRPP12YWT	rem.	12	2	0.1-0.3-0.5	0.3
CRPP14YWT	rem.	14	2	0.1-0.3-0.5	0.3

FZK: variation of W, Ti

CRPP: variation of Cr, Ti



## Oxide dispersion strengthened RAF(M) Steels - Main Conclusions -

ODS alloys	Advantages	Disadvantages
12-16% ODS ferritic steel	Higher operational temperature Better oxidation resistance	Anisotropic mechanical properties Poor fracture toughness
9% ODS ferritic/martensitic steel	Nearly isotropic properties after heat treatment Scaleable fabrication	Limited to temperature below ~700 C Marginal oxidation resistance at high temperatures Poor fracture toughness

Both ODS alloys promise much better radiation resistance against ductility reduction as RAF(M) steels without nano-dispersoides

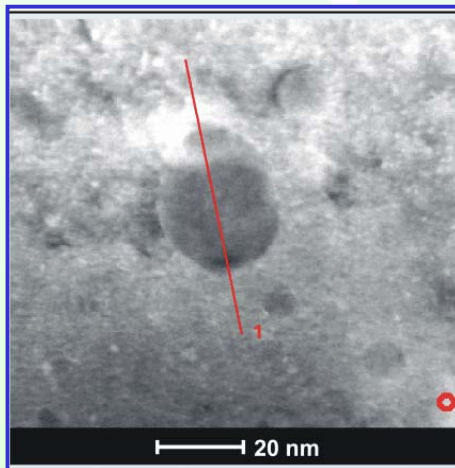


## ODS RAFM Steels

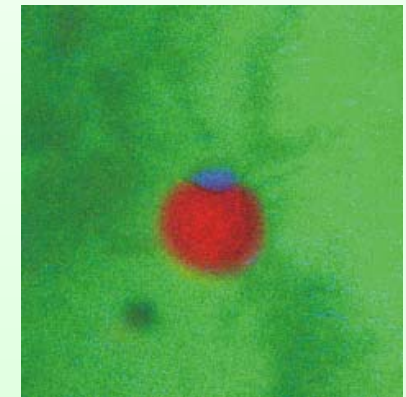
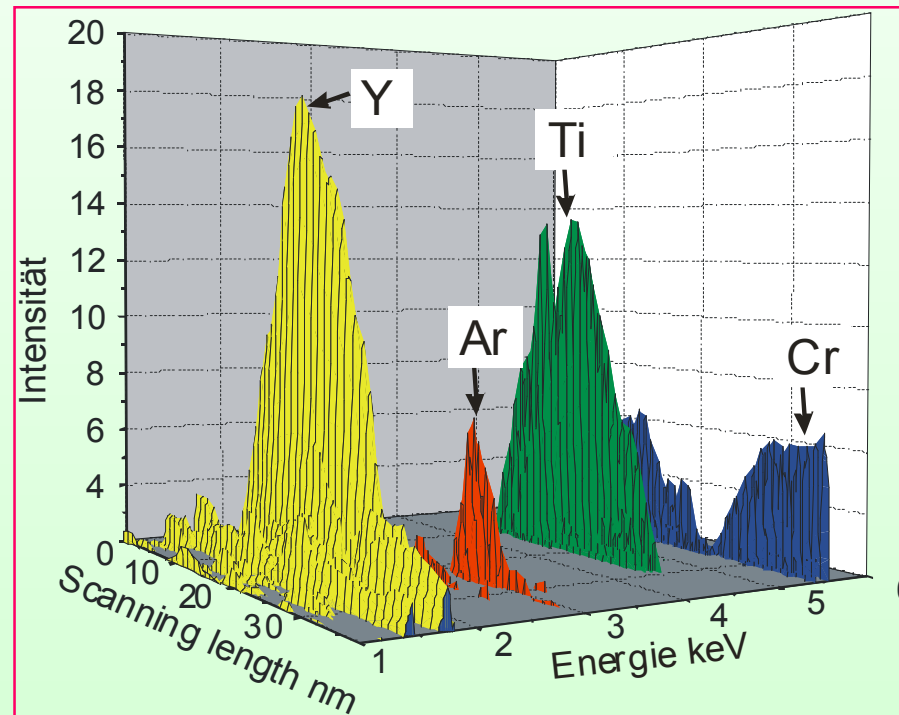
## TEM Element Analysis

- Imaging of Ar in Nano-Bubbles -

TEM Bright field



Energy Filtered TEM (EFTEM)



■ Fe ■ Ar ■  $Y_2Ti_2O_7$

M. Klimiankou, FZK

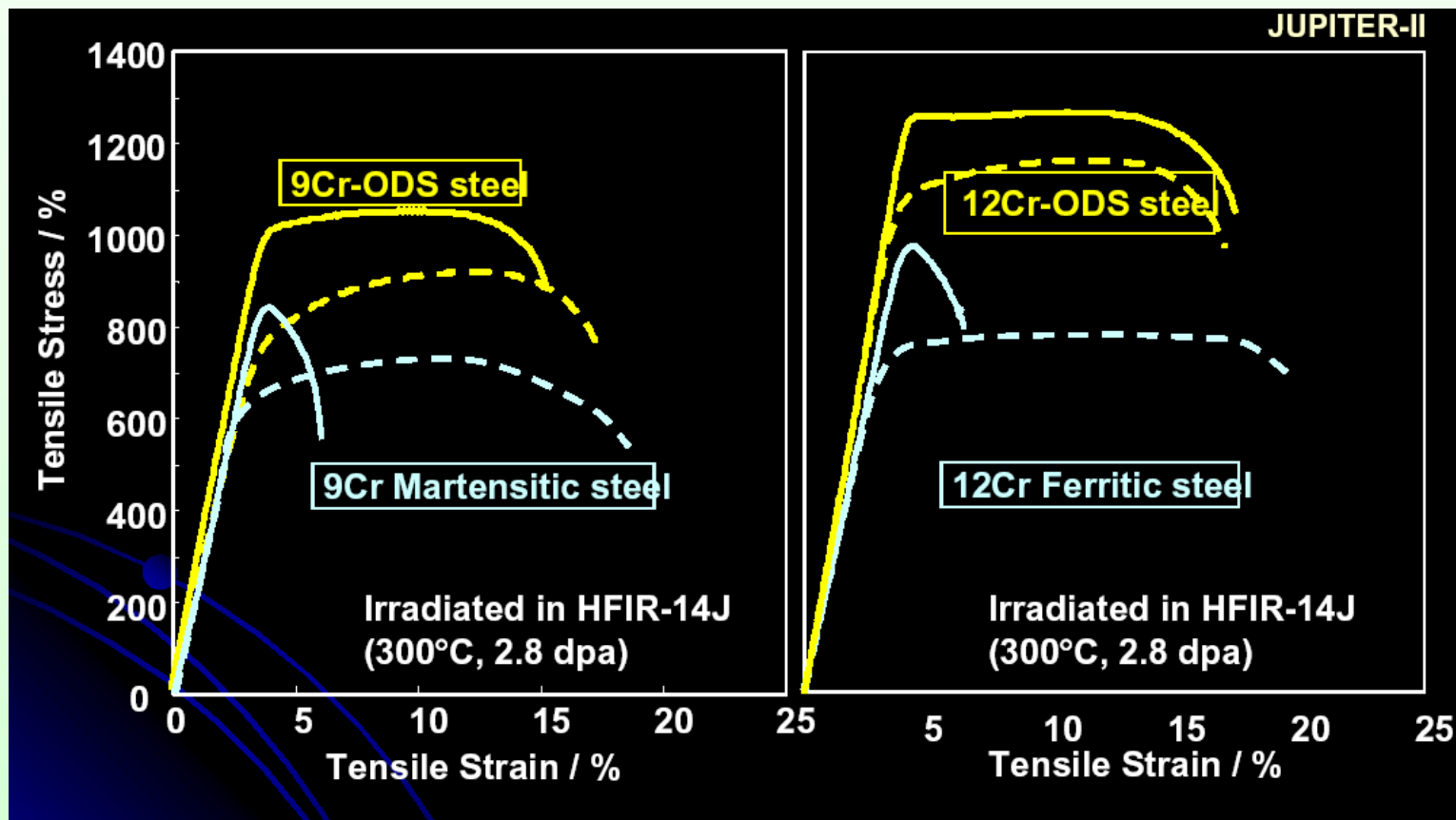
- Usually (not in ODS-EUROFER) Ar gas is used during mechanical alloying
- Hope: Nano-dispersoides ( $Y_2O_3$ ,  $Y_2Ti_2O_7$ ) are also very effective trapping centers for helium during irradiation (→ suppression of He embrittlement)



## ODS RAF(M) Steels

## Neutron Irradiation

A. Kimura et al, ISFNT-7, May 2005



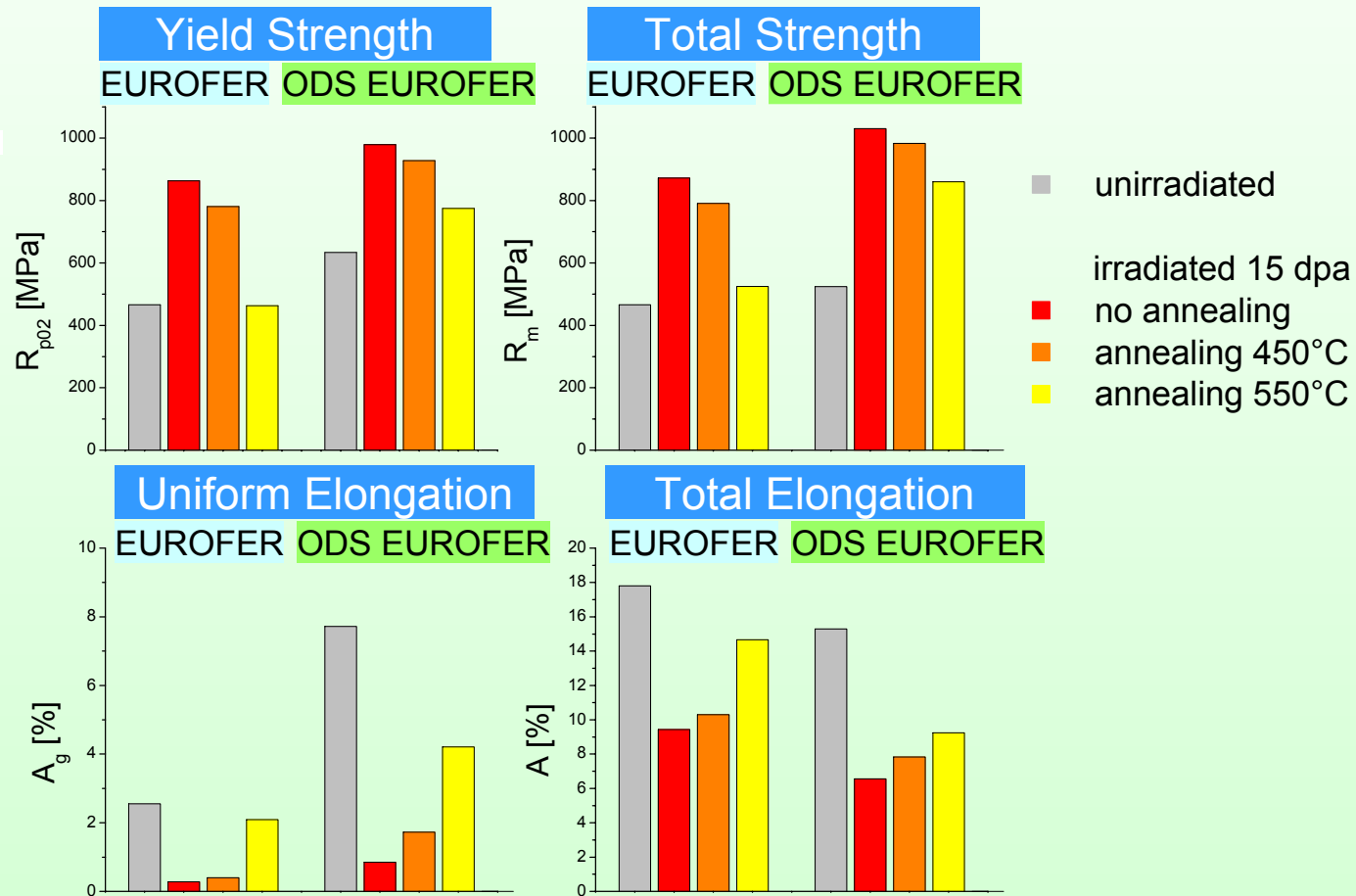
- Outstanding result of lower dose irradiation:  
Despite of Radiation hardening:  
ODS-RAFM alloys show almost no ductility reduction



## ODS RAFM Steels

## Neutron Irradiation

C. Petersen et al, ICFRM-12, Dec. 2005



- Outstanding result of medium dose irradiation (15 dpa at 320 °C):  
Despite of irradiation hardening: ODS-EUROFER (although non-optimized first batch) shows much less reduction of uniform elongation as EUROFER



## Conclusions and Outlook

- ➔ **ODS-variants of EUROFER would allow higher operational temperatures up to 650°C compared to EUROFER.**
- ➔ **The problem of an unfavourable DBTT has been improved considerably by applying an appropriate production route and heat treatment.**
- ➔ **A suitable technique to join EUROFER and EUROFER-ODS has been successfully developed and tested. Other joining methods also promising.**
- ➔ **A 50kg batch of ODS-EUROFER in different product forms has been produced and is going to be characterised.**
- ➔ **Reduced Activation Ferritic 12-14% Cr ODS steels would allow to expand the temperature window to 700°C and more.**
- ➔ **First results from irradiation experiments are very promising.**